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Reducing Lead Exposure from Remodeling and Soil Track-in in Older Homes

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INTRODUCTION

Peeling paint or broken plaster can cause toxic lead (Pb) exposure for the child with pica (the tendency to eat non-food items). However other toddlers may still receive a high exposure from Pb in house dust (Pb D) generated by remodeling and track-in of contaminated soil. The U S Agency For Toxic Substances and Disease Registry (ATSDR) which is associated with the Centers for Disease Control, estimates that 17% (2,400,000) of the small children in the United States still experience Pb poisoning, with blood Pb (PbB) levels above 15 micrograms per deciliter (μg/dl)[1]. Some 11% of the fetuses have similar health risks because their mother's PbB exceeds 10 μg/dl. Impaired metabolism, growth, IQ, and neurobehavioral development have been observed even though there are no medical symptoms at such PbB levels.

Children from all income groups who live in older homes have a higher risk of lead-induced learning disabilities[1]. Remodeling an old house is a common way in which middle income families expose their toddlers and fetuses to health risks from Pb dust. The U S Consumer Products Safety Commission published safety alerts in 1989 and 1990 on the hazards of do-it-yourself removal of Pb based paint and reducing exposure to Pb in paint. Parents reported to the authors that their preschool children who were living in two homes during removal of Pb paint subsequently had PbBs of 37 and 54 μg/dl. The Pb D concentration measured 8,000 to 10,000 ppm after removing paint from one room in one of the homes. This family spent about $25,000 to remove Pb paint from the rest of the house. When they had finished and done a through cleaning the PB D measured over 20,000 ppm.

Lead paint on older housing is a major source of childhood lead poisoning. Typically over 50% of the pre-school children in large American cities live in housing built before 1950[1]. The Pb in paint in such houses contaminates the soil (Pb S) around the foundation and the house dust. Auto traffic may have added more Pb than paint to soil and house dust in the average house in good condition in the center of a large city. An average for Pb S of 900 ppm was found three feet from the foundation of older homes where there was high auto traffic density in Minneapolis compared with 100 ppm for homes of the same age in a small community[2].

Atmospheric Pb deposited on the roof and outside walls of homes appears to wash down and concentrate in foundation soil. The Pb S concentration is higher nearer the foundation than at the road side[2]. This Pb and other toxics in soil are tracked into the house dust and ingested by young children because of their hand-to-mouth activity. Davidson and Elias estimate that a 2 year-old child who lives in a clean home gets over 40 times as much Pb from ingestion of dust as he does from breathing air[3].

It appears that Pb D loading in the rug where the child plays is the best single predictor of PbB. The PbB of 97 two-year old English children showed correlations as follows: Pb D loading on the floor in μg Pb/m^2 (r=0.46), Pb D concentration in ppm (r=0.21), and on hands (Pb H) (r=0.34). This study also found that Pb H correlated better with Pb D loading (r=0.44) than with Pb D ppm (r=0.24)[4]. At a given Pb S level, toddlers who mouth objects the most may have 2 to 3 times the PbB response of those who mouth the least[5].

Two studies show an average accumulation rate for total house dust in rugs of 1.2 and 1.6 g/m^2/day[6,7]. This compares with a mean indoor dustfall rate of 0.02 g/m^2/day measured in 100 homes in five cities[8]. The striking difference between indoor dust deposition and accumulation rates suggests track-in as a major source. One study of lead in house dust which compared the deposited (9.3 μg Pb/m^2/day) and accumulated (166 μg Pb/m^2/day) levels concluded that most of the Pb is carried into the house on shoes[9].

ATSDR and Davies et al. report that wooden houses have rug Pb D loadings (μg Pb/m^2) and concentrations (ppm) that increase with the house age, deterioration, area of exposed soil, recent interior painting, and remodeling[1,4]. Remodeling raised the average PbB of 13 toddlers by 4.8 μg/dl (SE=2.2, P=.02)[10]. The increase in Pb D loadings may last several months after the remodeling has been completed even with above normal cleaning[11].

Reduction of the Pb in paint, gasoline, and food have decreased Pb poisoning incidence. However, Pb from paint continues to accumulate around older houses and Pb from past auto emissions remains on the surface of urban soil (150 to 300 ppm in midyard and 900 ppm near the foundation) indefinitely[1,2,3,12]. These sources present significant health risks for children[1].

Control methods for Pb D include improved personal hygiene and housekeeping, stopping track-in, removal or covering of Pb paint, and removal or covering of Pb contaminated soil near older homes. However, the degree of Pb D reduction achieved by specific measures has not been evaluated. This study utilizes regression analysis to determine the effect of Pb D sources and control measures observed in homes.

METHODS

House Dust and Soil Sampling

A total of 51 pairs of house dust and soil samples were collected between Aug. 1988 and October, 1990 from 37 Seattle, WA.

and 5 Port Townsend, WA. homes built before 1950. Multiple tests were done on three homes where the family began removing their shoes at the door. All houses were in average or good condition. ASTM Method F608-79 was modified and used for measuring the dust loading in g/m^2 in rugs and the precision tested[7]. An upright Hoover Convertible vacuum cleaner was used to collect the dust from rugs. Five one ml samples of soil were collected from five separate areas from the top centimeter within one foot of the house's foundation. The soil and house dust samples were passed through a 100 mesh screen to retain the fraction < 150 microns for Pb analysis. Such fine dust is more likely to stick to a child's hand[13].

The dust samples were analyzed by Energy Dispersive X-ray Fluorescence (XRF). Calibration of the XRF instrument for house dust was performed by using Pb-free sand spiked with Pb. Standard soil samples prepared by the US Environmental Protection Agency (EPA) Region I Laboratory were used to calibrate the XRF instrument for soil samples as described by Spittler and Feder[14].

Regression Variables

The Pb D surface loading (μg Pb/m^2) of a carpet was determined as the product of the fine (<150 μm) dust surface loading (g/m^2) vacuumed from the carpet and the lead concentration ($\mu g/g$ = ppm) of this fine dust. A total of 51 lead dust loadings suitable for regression on other simultaneous measurements were obtained from 42 different houses and apartments. Table I lists nine other variables measured, observed, or reported by the resident along with each lead dust loading: the lead concentration of surface soil (Pb S) near the foundation, house age, exterior siding, remodeling in last 12 months, carpet type, vacuum cleaner type (all possessed a vacuum cleaner), peeling paint indoors, whether shoes were removed at the door, and existence of a walk-off mat (consisting of hall carpeting in an apartment building). Other variables obtained included days since the carpet was last vacuumed, number of household members, outdoor peeling paint, city, and a traffic index (summation of traffic rate in cars per day divided by distance to the road for the nearest street and any nearby highways). The mean, standard deviation, and range of values obtained on the 51 observations are also presented in Table I for the variables important enough to enter stepwise regression models for the natural logarithm of lead dust surface loading, ln (Pb D Load).

Stepwise Regression Analysis

Stepwise regression models for the dependent variable, ln (Pb D Load), were formed as linear combinations of subsets of the 18 available independent variables using the SAS/STAT procedure

S were used to convert their highly skewed distributions to nearly symmetrical log-transformed distributions. The regression assumption of equal error variance for all observations of the dependent variable appears valid for ln (Pb D Load), but would have been grossly incorrect for Pb D Load itself.

CORRELATIONAL ANALYSIS RESULTS

An initial correlation analysis showed that nearly all pairs of independent variables were relatively uncorrelated with each other in the 51 observations ($|r| < 0.45$). The single exceptional correlation among the independent variables listed in Table I was $r = -0.85$ of wood siding and walk-off mat/ apartment. These variables are largely confounded because all sampled buildings had exterior wood siding, except three with brick siding: the apartment building with carpeted hallways comprising the walk-off mat in which 11 observations were made and two homes with a total of three observations. Four variables had strong pair-wise correlations with ln (Pb D Load): remove shoes at door ($r = -0.62$), wood siding ($r = 0.53$), ln (Pb S) ($r = 0.50$), and walk-off mat/apartment ($r = -0.48$).

Table I Regression variables (n= 51 observations)

Variable	Values of Variable	Mean (± Std. Dev.)	Minimum	Maximum
Pb D Load = Lead dust surface loading in carpet	$\mu g\ Pb/m^2$	13,500 ± 29,700	20	147,000
Ln (Pb D Load) = Natural logarithm of lead dust loading	ln ($\mu g\ Pb/m^2$)	7.30 ± 2.40	3.00	11.90
Pb S = Lead concentration in foundation surface soil	μg Pb/g (= ppm)	3,090 ± 10,200	150	74,000
Ln (Pb S) = Natural log of lead soil concentration	ln (ppm)	7.15 ± 1.05	5.01	11.21
House age	years	69.8 ± 16.1	40	93
Wood siding outdoors	0=no, 1=yes	0.73 ± 0.45	0	1
Remodeling indoors (in last 12 months)	0=no, 1=yes	0.25 ± 0.44	0	1
Carpet = flat rug on bare floor	0=no, 1=yes	0.24 ± 0.43	0	1
Vacuum sweeper with agitator bar	0=no, 1=yes	0.82 ± 0.39	0	1
Indoor peeling paint	0=no, 1=yes	0.14 ± 0.35	0	1
Remove shoes at door	0=no, 1=yes	0.27 ± 0.45	0	1
Walk-off mat/apartment*	0=no, 1=yes	0.22 ± 0.42	0	1

*Hall carpeting in apartment building was the walk-off mat.

Regression Models

Table II presents the two optimal regression models for ln (Pb D Load) obtained by stepwise model selection in the sense of minimum C_p statistic. Model 1, produced by unrestricted stepwise selection, has a coefficient of multiple determination $r^2 = 0.71$; its prediction equation is:

$$\ln(\text{Pb D Load}) = 1.61 + 1.06 \ln(\text{Pb S}) - 2.18\,(\text{Remove Shoes}) - 1.86\,(\text{Walk-off Mat}) - 1.12\,(\text{Agitator Vacuum Sweeper})$$

Model 2 presented in Table II was obtained by restricting the walk-off mat/apartment variable, since its effect is confounded with the wood siding variable. With seven independent variables, Model 2 explains more of the ln (Pb D Load) variation ($r^2 = 0.76$) than Model 1, as expected, but also has a better C_p statistic, suggesting better predictive power.

Both optimal models contain ln (Pb S) and Remove Shoes as regression variables. Their coefficients are similar in magnitude in both models. These models imply that the lead concentration of surface soil near the foundation and wearing shoes indoors both affect the Pb D surface loading of carpets in the home. The Walk-off Mat/Apartment variable in Model 1 and the Wood Siding variable in Model 2 reflect the confounded effect of walk-off mat/apartment and brick (vs. wood) exterior siding in reducing the lead dust loading of indoor carpets. The other variables in both models also appear to have some effect on carpet Pb D loading, but our 51 observations are inadequate to discriminate their separate effects.

Effect of Model Factors on Pb D Loading

Since ln (Pb D Load) is predicted as a linear combination comprised largely of 0/1 variables in both models, the exponential of the coefficient of each 0/1 variable provides a point estimate of the factor by which its presence increases or reduces the carpet Pb D loading. Since ln (Pb S) appears in both models, it can be shown that a point estimate of the effect on the carpet Pb D loading of a factor change in the soil lead concentration (Pb S ratio) is given by the Pb S ratio raised to the coefficient of the ln (Pb S) variable. The estimated factor effects of each regression variable on Pb D Load are presented in Table III.

Since the coefficient of ln (Pb S) is close to 1.0, both models indicate that the carpet Pb D loading is nearly proportional to the Pb S concentration in the study homes, after adjusting for other modifying factors. Removing shoes at the door produced approximately a ten-fold reduction in the carpet Pb D loading in the study homes (9-fold reduction by Model 1 and 13 fold by

Table II Optimal regression models for natural logarithm of lead dust surface loading; ln (Pb D Load) in ln (μg Pb/m2)

	Coefficient (± Std. Error)	
	Model 1	Model 2
Regressor Variables in Model		
Intercept (b_0)	1.61 (± 1.39)	-2.12 (± 1.58)
Ln (Pb S conc.)	1.06 (± 0.18)	0.88 (± 0.18)
Remove shoes at door	-2.18 (± 0.46)	-2.55 (± 0.45)
Walk-off mat/apartment	-1.86 (± 0.49)	
Wood siding		1.67 (± 0.45)
Agitator bar on vacuum cleaner	-1.12 (± 0.53)	
Remodeling (in last 12 months)		1.19 (± 0.43)
Flat rug on bare floor		1.47 (± 0.51)
House age		0.026 (± 0.013)
Indoor peeling paint		0.83 (± 0.54)
Model Statistics		
Coefficient of multiple determination	$r^2 = 0.71$	$r^2 = 0.76$
Mallow's C_p statistic	$C_p = 4.1$	$C_p = 2.3$

Table III Estimated factor by which variable affects lead dust surface loading (μg Pb/m2)

	Average Factor Effect on Pb D Load*	
Variable	Model 1 ($r^2 = 0.71$)	Model 2 ($r^2 = 0.76$)
Soil lead conc. (Pb S)	$(\text{Pb S ratio})^{1.06}$	$(\text{Pb S ratio})^{0.88}$
Remove shoes at door	8.9	12.8
Walk-off mat/apartment	6.4	
Wood siding		5.3
Agitator bar on vacuum cleaner	3.1	
Flat rug on bare floor		4.3
Remodeling (in last 12 months)		3.3
House age		1.03/year
Indoor peeling paint		2.3

*Factor = exp (coefficient) for all 0/1 variables.

by Model 2), presumably by preventing track-in of outdoor soil. The confounded walk-off mat/apartment/brick siding effect reduced Pb D loading by 5 or 6-fold in the study homes. The presence of an agitator bar on the household vacuum cleaner reduced carpet Pb D load in these homes by about 3-fold. Alternatively, placing a flat rug on a bare floor, remodeling in the past year, and indoor peeling paint each appeared to produce an average 2 to 4-fold increase in Pb D loading in the study home's carpet. Each year of increase in the age of a study home was associated with an average 3 percent (1.03 fold) increase in carpet Pb D load.

Crude Effect of Factors on Pb D Loadings in Rugs

A subset of Pb exposure data collected in 1988 and 1989 from 37 homes is summarized in Table IV. Total and fine dust loading, Pb D loading, Pb dust ppm, Pb S ppm, house age, and number of people in the house are shown for homes with shoes off, shoes on, with walk-off mat, and remodeling. This chart allows a crude assessment of comparative risk in a home if similar methods are used to collect and analyze the house dust. However, many of the factors identified in Table III are not accounted for in the columns in Table IV. Therefore these comparisons are crude.

Occupants who remove shoes place a higher value on cleanliness which may be reflected in other actions to control dust. The soil ppm were lower in homes where the shoes were taken off. Thus the effect of shoe removal is unlikely to be as large as shown in Table IV. Other aspects of apartment life, such as fewer children and pets and less access to outdoor soil, may contribute to the effect attributed to the walk-off mat.

The exposure to Pb in rugs varied by a factor of over 4000 from house to house (32 to 147,000 $\mu g/m^2$). The high rug Pb loading came from removal of a wall in the home one month before the sample was collected. The soil Pbs varied by a factor of 490 (150 to 74,000 ppm). The high Pb S was associated with sanding the paint off the siding as well as 5500 ppm and 121,000 ug Pb/m^2 in the rug in this home. The importance of factors which affect such exposures are listed in Tables III and IV.

Removal of shoes and mats reduced the total dust, fine dust, and ppm Pb in the house dust. Remodeling in 9 older houses gave a geometric mean of 12,600 ug/m^2 and an average of 35,100 ug/m^2 for Pb D. Peeling paint was reported on the outside of 8 and on the inside of 6 homes. Six out of eight homes with the highest Pb D loadings had been remodeled in the last year and one had peeling paint on the inside. Use of a canister vacuum without a power head in 8 homes produced a Pb D geometric mean of 5500 ug/m^2 and average of 15,100 ug/m^2.

Table IV. Factors related to PbD loadings in rugs.

(Averages)	Shoes Off	Shoes On	Mat	Remodel
No. of homes	5	32	6	9
Total Dust Loading g/m^2	3.5	26	6.7	63
Fine Dust Loading g/m^2	0.8	10	1.7	32
Fine Dust Pb Loading ug/m^2	310	10,700	580	35,100
Fine Dust Pb Conc., ppm	320	780	430	1,320
Fine Soil Pb Conc., ppm	860	1,530	1,350	2,140
House Age in years	73	71	76	72
No. People in Home	3.0	2.8	1.3	3.2

DISCUSSION

The importance of remodeling in elevating Pb D loading has been underestimated in our analysis. The factor of 3 increase indicated by model 2 (see Table III) was obtained by grouping together remodeling of different magnitudes which was in progress, recent, or had occurred up to 12 months earlier. Separating out remodeling by magnitude and time would have given a more realistic factor for recent remodeling.

The occupants of three homes tested on the initial sampling in 1988 began removing their shoes upon home entry for at least five months prior to a second Pb D measurement of their carpets. The Pb D geometric mean dropped from 17,100 to 250 μg Pb/m^2 in these homes. One of the homes also placed a walk-off mat at the front and back door and vacuumed twice a week. It was sampled on 8-88, 2-89, and 4-90 with following readings: 7800, 160, and 32 μg Pb/m^2. It appears that it took more than a year to remove the reservoirs of Pb in the rug and house after the track-in had been controlled. Exposure to Pb D in the rug was reduced by a factor of 240 in this home. Two other families that removed shoes and used an upright vacuum had Pb D loadings below 100 $\mu g/m^2$.

Table III suggests the effectiveness of various measures to control carpet Pb D loading. Provided the causative variable (rather than an associated variable) was being measured in our study, similar degrees of effect of these variables on Pb D load may be anticipated elsewhere in the United States and other developed countries. Davies et al. found similar concentrations of Pb in dust in a study in the England[4]. They also found the Pb ppm in the doormat was about twice that on the floor inside. Such data tends to support track-in as a major source of floor Pb in homes. Track-in of contaminated soil may be a major source of exposure for children who live in Eastern Europe. This may be one major source of exposure that most families can afford to control. The main requirements are knowledge and commitment.

No direct association of Pb D loading was observed with such outdoor variables as the traffic index and outdoor peeling paint. A preliminary regression analysis suggests that ln (Pb S) was associated with city size, house age, and outdoor peeling paint in our 51 observations. Consequently, these outdoor Pb sources may exhibit some effect on Pb D loading in our study via the intermediary of the lead concentration of surface soil near the home's foundation.

The soil around the five houses in Port Townsend averaged 350 ppm Pb compared with an average of around 1900 ppm in 37 Seattle homes. The average age of the Seattle homes (70 years) was nearly identical with the homes in the smaller community of just over 5000 people. This limited data set tends to suggest that older housing in large cities will tend to have greater amounts of Pb in soil and house dust as noted in the Minnesota study[2].

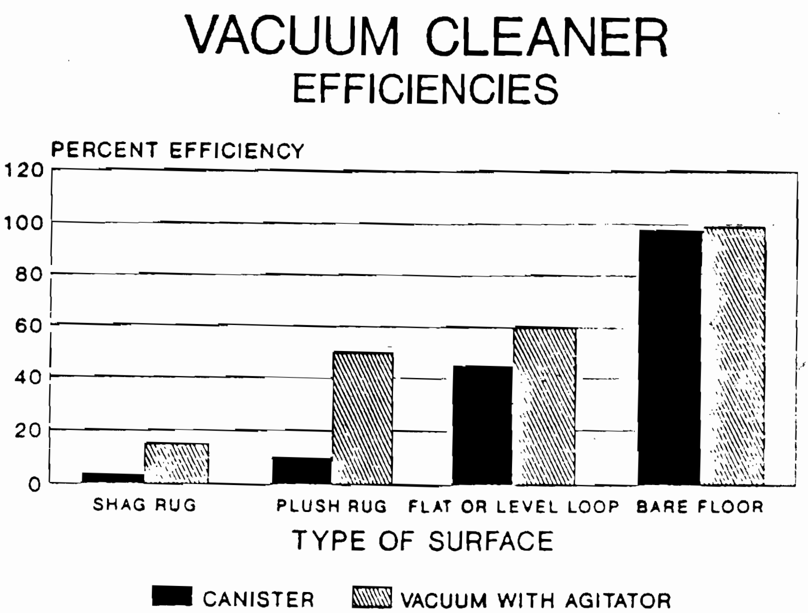
The dust loading (g/m^2) on a rug can be 100 times greater than the loading on a bare floor in the same home[7]. However the amount of dust and Pb found on carpets on bare floors tends to be higher than average for two reasons: 1) rugs tend to retain dust tracked from the bare floor and 2) vacuums without an agitator which are used to clean bare floors are also used to clean the rug. Such vacuums leave more dust behind (see Figure 1 below).

CONCLUSIONS & RECOMMENDATIONS

Charney et al. established that good personal hygiene and housekeeping can significantly reduce PbD loadings on surfaces in homes and PbB in children[16]. The data presented here suggest that the control of track-in by removal of shoes or use of a walk-off mat will magnify the effect of cleaning by a factor of ten, or perhaps six respectively, in reducing Pb exposure of children and adults. The cost of taking off ones shoes or a walk-off mat ($20 to $175) is low compared with cost of removing Pb paint ($10,000 to $25,000) or soil ($350 to $1,400)[1]. These are actions which can be taken while waiting for the financing of paint removal. Removal of shoes is more effective but use of a mat may be more acceptable to American families. The combination of controlling track-in and improved cleaning methods may produce a 100-fold reduction in rug Pb exposure over a period of time.

The cost of controlling dust levels in commercial buildings and homes is reduced by stopping track-in. A vacuum with an agitator may cost only $100 and pick up 2 to 6 times as much dust from a rug as a canister vacuum. Figure 1 shows the estimated efficiencies of the canister and vacuums with an agitator on various surfaces[17]. Level loop carpets are easier to clean and last longer than plush rugs. Flat rugs and bare floors are the easiest to clean but the rugs increase risks if the canister vacuum is used on the rug. Data suggests that 25% of older homes will have one or more of the following adverse exposure factors: a canister cleaner, shag rug, vacuum with a lose belt or full bag, vacuuming

Figure 1 Vacuum cleaner efficiencies by type of surface.



less than once a week, or no vacuum cleaner. Such homes may have high dust levels and rug Pb exposures above 10,000 $\mu g/m^2$.

The broad distribution of the Pb D loadings in our study indicate that a questionnaire could be used as an initial screen to find the homes with a high risk of elevated PbB in a toddler. The stepwise regression models presented here provide a basis for evaluating the variables in the questionnaire that influence Pb D in order to predict Pb exposure. A questionnaire may cost $5, a PbB test $25, and a house dust test $50 to $150. ATSDR recommends that all preschool children who live in older houses have their blood tested[1]. However when there are budget limitations, the use of the questionnaire may be a cost effective and quick way to locate the high risk children in greatest need of a blood test. Pediatricians and public health workers could also use the questionnaire to assist parents in assessing and controlling the potential health risks for toddlers in the home.

Do-it-yourself remodeling or peeling paint in an old home can be dangerous for the learning ability of a small child. Such homes may require repair, rug removal, repeated cleaning over many months, and testing to make them relatively safe for a child. Extensive training is required to do such jobs safely. Normal cleaning is not adequate to protect a toddler during or after remodeling. Replacement of contaminated rugs may be cost effective because it takes so much labor and time to reduce the Pb loading. Testing is required to determine the Pb in a rug that has been exposed to remodeling in an old home. The states of Maryland, Minnesota, and Massachusetts have established regulations for Pb abatement as well as Pb dust and paint removal to protect children. Maryland set a cleanup standard of 200 $\mu g/ft^2$ for floor dust after Pb abatement[18].

It is recommended that:
1. EPA develop a) a questionnaire to assess risk from Pb in the home for use by parents, health workers, and doctors, b) guidelines for Pb dust action levels, c) a standard method for sampling Pb in rugs, and d) simple tests for parents to monitor Pb and dust in rugs.
2. A study be done to determine the effect on infants' blood Pb of removal of shoes at the door, use of booties over shoes, large walk-off mats, and dust monitoring to reinforce action by families.
3. Parents, doctors, and health workers be alerted to the health risks of soil track-in, remodeling, broken plaster, paint removal, peeling paint, painting, track-in, canister vacuums, and Pb exposure in older homes.
4. Video training courses be created by EPA for architects, builders, and do-it-yourself remodelers on control methods for Pb dust.

A standard method is needed for monitoring the Pb, pesticides, and other toxics in house dust to understand and reduce the total exposure of children. It is not possible to compare one study with another or to establish guidelines for the protection of health without a standard method. A High Volume Surface Sampler (HVS2) and methodology were developed and field tested for the U S Environmental Protection Agency (EPA) as part of the Non-Occupational Pesticide Exposure Study (NOPES)[19,20]. Information gathered with the HVS2 on exposure to pesticides in house dust in nine homes caused the emphasis in NOPES to shift from indoor air exposure of adults to a House Dust/Infant Pesticide Exposure Study (HIPES) which was conducted at Research Triangle Park, NC during the fall of 1990.

A second generation Small High Volume Surface Sampler (HVS3) has been developed for EPA for use with the HIPES study that is easier to carry, clean, use, and buy. It showed an efficiency of 67 to 69% for fine dust embedded into carpets and retained more than 97% of the pesticides aldrin, chlordane, chlorpyrifos, dieldrin, and heptachlor; and over 99.8 % of the Pb in the collected dust in laboratory tests[21]. The HIPES pilot study has been discussed by Lewis et al[22].

Toddlers play on rugs and mouth their hands. Toxics in dust are directly ingested by children, without passing through the air, water, or food. There is a need to monitor and control the quality and quantity of our dust as well as the quality of our air, water, and food to protect children. Control of Pb D from soil track-in and remodeling is essential to protect small children and fetuses.

Cleaning and control of track-in are especially important in older homes in large cities or other high traffic areas or near Superfund sites. Action to reduce even low levels of Pb exposure may protect the child's IQ[1,23]. Control of dust and track-in may also help to reduce exposure to pesticides used in the lawn and garden, toxics coming from wood smoke and industry, termiticides injected near the foundation, toxics tracked home from the job, mutagens, dust mites, allergens, and sick building symptoms that are associated with dust[7,18,24,25]. Control of dust may be an environmental best buy for families who live in older homes.

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